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Simulation of single-lap-joints of carbon fibre tapes under tensile loading

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Due to their high automation potential and increased manufacturing speed, unidirectional (UD) thermoplastic tape placement technologies appeared as a promising alternative with potential for large-scale component production. These processes offer the chance of tailoring mechanical properties to a high degree, by sequentially addition of tapes in the desired orientation [1]. Several strategies to optimize the fibre orientation in order to maximize a specific design variable (e.g. stiffness) can be found in literature [2]. Independently of the strategy employed to optimize the tape placement, tape-to-laminate joints and tape-to-tape joints will be inevitable present on the final part. Moreover, in order to follow an optimal path, overlaps will surely not be rectangular in all cases. Whereas several studies have focused their efforts on the tape-to-laminate and design stages, no study has yet addressed the problem of joining UD tapes.

In this study, the strength dependence on the overlap geometry and the manufacturing pressure of single-lap-joint (SLJ) assemblies of carbon fibre reinforced thermoplastic tapes was characterized. SLJ assemblies with rectangular and rounded overlaps (but same overlap areas) were prepared employing forming pressures from 3 to 100bar.

Hashin's failure criterion [3] was used to model the failure of the assemblies. An optimization algorithm was developed to calibrate the failure criterion for each manufacturing pressure. The same consists of an iterative procedure where both geometries are iteratively simulated and the results, compared with the experimental data. In case the reduction of the cost function or the improvement of the solution is smaller than established tolerances the process stops. When the convergence conditions are not satisfied the failure parameters are modified using a trust-region optimization algorithm and the simulations are recomputed iteratively until one of the convergence conditions is achieved.

Delamination was not observed during the SLJ tests, indistinctly of the manufacturing pressure and the adherend geometry employed. Instead, fibre fracture was identified preferentially also at the end of the overlap, this agrees with the results of Wang et al. [4] who studied the strain/stress concentration at overlap ends.

The strength of the assemblies was characterized in terms of the ultimate tensile strength (UTS), defined as the maximum load reached during the SLJ test per unit of cross-sectional area of one adherend. The UTS dependence on the manufacturing pressure is shown in Figure 1. Three regions can be clearly identified: i) for manufacturing pressures up to 10bar, almost no difference between strength of rectangular and rounded joints is observed; ii) a transition takes place between 10 and 20bar where strength becomes geometry dependent; iii) for manufacturing pressures of 20bar and higher, the strength of the rounded assemblies is

significantly lower. The transition between 10 and 20bar is of high practical importance. Considering the case of tape placement process integrated in a thermoforming line where tape-to-tape joints are present, these results allow to define forming limits for such operation.
Obtaining the failure parameters for each manufacturing pressure, the evolution of the failure envelope with the manufacturing pressure can be defined (Figure 2). It can be seen that the manufacturing pressure showed a large impact on the shear strength of the material.

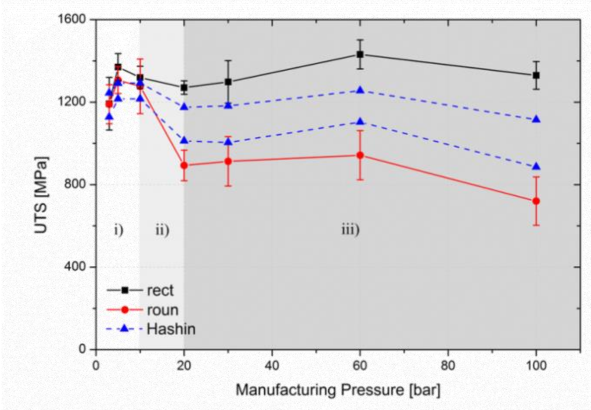

Figure 1. SLJ strength dependence on the manufacturing pressure.

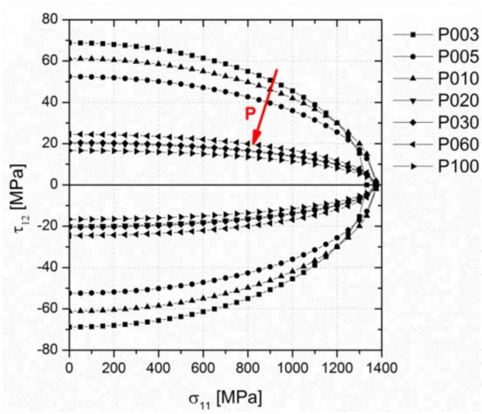

Figure 2. Failure envelope evolution with manufacturing pressure.

The present study showed that although adhesive failure is not likely within the analysed pressure range, overlap geometry and forming-pressure affect the strength of SLJ assemblies under tensile loading. For pressures beyond 20bar, fibre rotation was observed near the end of rounded overlaps, causing the reduction of the SLJ strength due to local off-axis loading.
The effect of the structural alteration produced during the joint preparation could be successfully modelled employing Hashin's failure criterion. The degradation of the strength caused by local off-axis loading is captured through a reduction of the shear strength in Hashin's Model. This approach has the advantage of disregarding the microstructural aspects, making its use more practical but still accurate to predict the failure of tape assemblies.

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